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Recent results on 0°C isotherm height for slant path rain attenuation

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Abstract : The results on 0°C isotherm height over selected stations in India for different seasons, have been presented in this paper Such observations on 0°C isotherm height were derived from radiosonde data The variation of 0°C isotherm height over different stations and seasons are considerable The effect of ground temperature on 0°C isotherm height has also been discussed The observed results are also compared with the results derived by using the well known theoretical models

These results on 0°C are needed for estimation performance of communication links for earth-space paths operating in higher frequencies Based on such results, the one way attenuation of radiowave due to rain having rain rate ~ 120 mm/h for earth-space path over Delhi has been estimated It is found that the attenuation varies from around ~ 21 dB to around ~ 63 dB while the rain height varies from about ~ 2 km to about ~ 6 5 km at 20 GHz

Keyword : 0°C isotherm height, rain attenuation, slant path

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1. Introduction

The results on rain height are important in deducing rain attenuation which is a major contributing factor accounting for link outages in satellite communication. Such results are needed for the estimation of attenuation of radiowave operating in frequencies higher than 10 GHz in earth space propagation mode. There is dearth of data on rain height over the Indian subcontinent. The rain height is equal to the 0°C isotherm height [1,2]. The rain is considered to be uniform from the ground to the rain height [1,2]. The rain height is estimated currently in relation to 0°C isotherm height. Such results are deduced from upper air measurements [1–3]. The upper air data are taken daily by the India Meteorological Department by using radiosonde system over various stations located in different geographical regions. Radiosonde flights are made twice daily one at 0000 GMT and the other at 1200 GMT corresponding to early morning and late evening local time.

The 0°C isotherm height for three stations, *viz.*, Bangalore, Calcutta and Delhi are estimated. Three stations are located in different geographical and radioclimatological regions. Delhi is located in northern plains having an elevation ~ 216 m and Calcutta is located on the coast with station height ~ 6 m while Bangalore is situated in southern plain with an altitude ~ 921 m. In this paper, results on 0°C isotherm height for aforesaid stations for different seasons are presented. It is seen that the 0°C isotherm height in monsoon varies from ~ 4.4 km to 6.3 km over these stations. There is considerable variation in 0°C isotherm height over the different stations during winter months. The 0°C isotherm height varies between ~ 3.66 km and 6.04 km over these stations during summer months. The rainfall from thunder storm are found above the 0°C isotherm and upto about ~ 10 km to 12 km. There is rainfall from low clouds which is below the 0°C isotherm height. The 0°C isotherm height is also estimated by using the wellknown model developed by Fedi [4]. This is not applicable for our subcontinent. The model developed by Crane [2] is also tested for interpolation for the estimation of 0°C isotherm height for the probability levels between 0.001% and 1% of the year for the three aforesaid stations.

2. Characterisation of different seasons

The variation of 0°C isotherm height in different seasons over Indian stations is due to the climatic variation. A brief on the climatic conditions in India in the different seasons is as follows [5]. A high pressure area is normally situated in the extreme northwest and relatively low pressure occur in the Indian seas during winter. The season is also known as the northeast monsoon season. Weather is generally fine over the whole of the country. The pressure gradient set up in the winter months and consisting of a high pressure over north India and low pressure over the Indian seas get disrupted in the pre-monsoon. The period in May just before the onset of the southwest monsoon, is a period of intense heat and occasional heat waves. The moist and warm current from the Indian ocean moves rapidly up in the beginning of the monsoon season. By the middle of July, monsoon (south west monsoon) establishes itself upto the extreme north of the country. The advance of the monsoon results in increase in rainfall over the country.

3. Distribution of 0°C isotherm height

The probability distributions of 0°C isotherm height for different periods including pre-monsoon, monsoon, winter and all months over Delhi (latitude 28.32°N) are presented in Figure 1. It is shown in Figure 1 that the 0°C isotherm height during all months varies from ~ 2.1 km to 6.3 km. The 0°C isotherm height over Delhi during pre-monsoon period is around ~ 4.3 km at 50% probability level. The 0°C isotherm height is found to be maximum during monsoon months while it is minimum during winter periods. The 0°C isotherm height is found to vary between ~ 4.8 km and 3.66 km from 1% to 99.99% probability levels during pre-monsoon months. It is thus seen that the variation of rain height over

Delhi during pre-monsoon months is not that appreciable while the variation is significant during monsoon and winter months. The results on 0°C isotherm height reported here

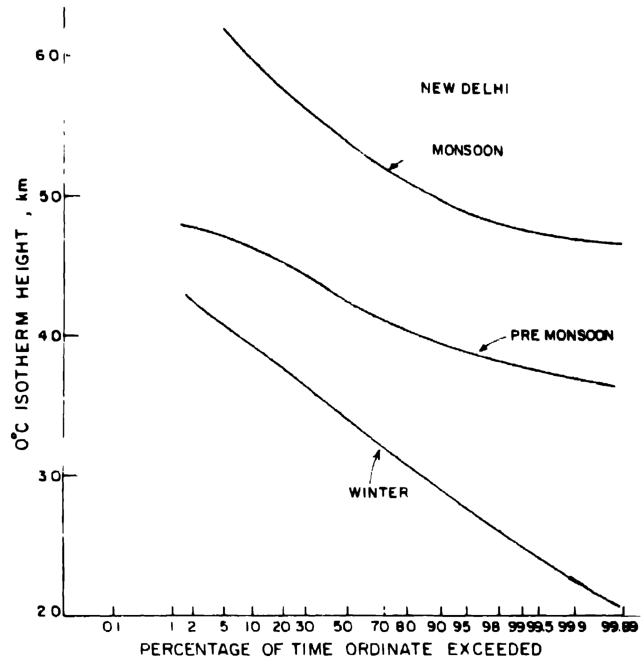

Figure 1. Distribution of 0°C isotherm height during different periods over New Delhi.

are useful to estimate the total attenuation over earth space path in the frequencies varying from 10 GHz to 400 GHz.

The summer and winter are very severe and monsoon is moderate in Delhi. The peak summer months are April and May over Delhi. The average temperature is 27°C and 31.5°C during 0000 GMT in April and May respectively, while it is 35.2°C and 39.3°C during 1200 GMT in April and May respectively. The winter is very severe in Delhi. The average temperatures in December, January and February during early morning are 11°C, 10°C and 13.5°C respectively. The monsoon over Delhi is moderate. The total rainfall over Delhi is 211 mm and 172.9 mm in July and August. The large variation of 0°C isotherm height suggests that the 0°C isotherm height is dependent on the micro-meteorology of rain and other meteorological features. The variation of meteorological parameters including temperature, humidity and rainfall are significant from season to season and in different hours of day and night.

Figure 2 illustrates the results on 0°C isotherm height over Calcutta (latitude : 22.39°) located in Indian east coast. The 0°C isotherm height is found to vary from 3.16 km to 5.94 km during all months over Calcutta. The probability distributions of 0°C isotherm height during pre-monsoon and monsoon months indicate that the rain height varies from

4.75 km to 4.98 km during pre-monsoon while during monsoon, the 0°C isotherm height varies between 4.70 km and 5.88 km. The 0°C isotherm height is found to be minimum during winter months and maximum in monsoon.

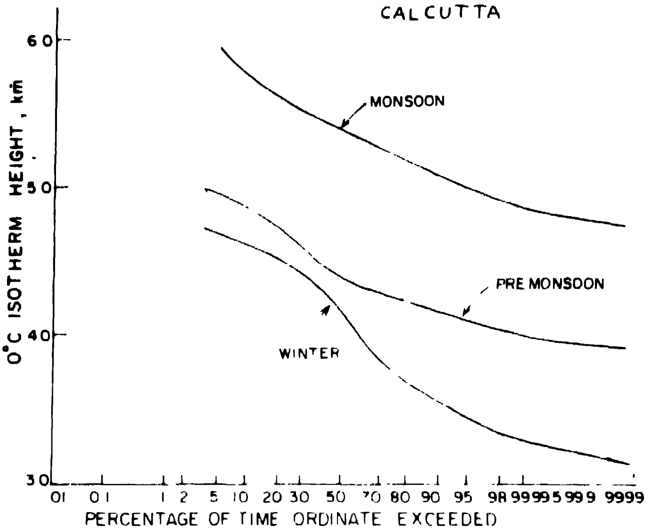

Figure 2. Distribution of 0°C isotherm height during different periods over Calcutta

The summer and monsoon are very well-defined and winter is mild in Calcutta. The three months consisting of December, January and February in a year, constitute winter period in Calcutta. The average temperatures, in Calcutta in December, January and February are 18.4°C, 17.3°C and 20.5°C during 0000 GMT and 21.7°C, 22.3°C and 26.2°C during 1200 GMT respectively The values of average relative humidity during December, January and February are 76%, 78% and 75% during 0000 GMT and are 65%, 56% and 48% during 1200 GMT respectively. The summer months in Calcutta are April and May and are associated with lot of humidity. The average temperatures in April and May are 29.6°C and 30.6°C during 0000 GMT and they are 32.3°C and 31.9°C during 1200 GMT respectively. The monsoon months are July and August in Calcutta. The total rainfall over Calcutta in July and August are 300.6 mm and 306.3 mm. The seasonal variation of 0°C isotherm suggests that the 0°C isotherm height is strongly dependent on seasonal meteorological parameters.

The results on 0°C isotherm height for different periods over Bangalore (latitude : 12.58') are illustrated in Figure 3. It is found that the 0°C isotherm height varies from 4 4 km to 6 05 km during all months. One of the interesting features is to note that there is not much seasonal variation on 0°C isotherm height over Bangalore.

The weather characteristics are different in Bangalore than Delhi and Calcutta. The winter, summer and monsoon are mild in Bangalore. The average temperatures are 24.7°C and 24.3°C in April and May respectively during 0000 GMT and they are 31.0°C and 29.9°C in April and May during 1200 GMT. The average temperatures are 18.8°C, 18.4°C and 20.4°C in December, January and February during 0000 GMT. The monsoon period in Bangalore is July and August and total rainfall in those months are 116.6 mm and 147.1 mm respectively. The seasonal variation on 0°C isotherm height is not appreciable

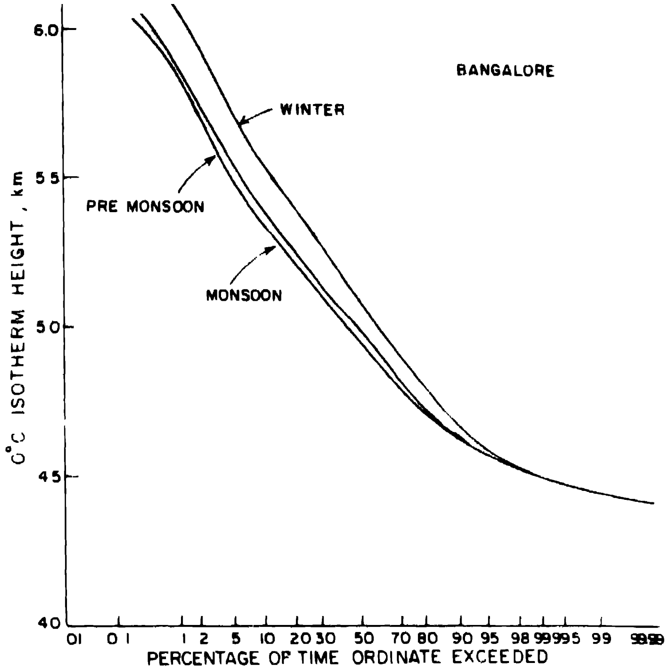

Figure 3. Distribution of 0°C isotherm height during different periods over Bangalore

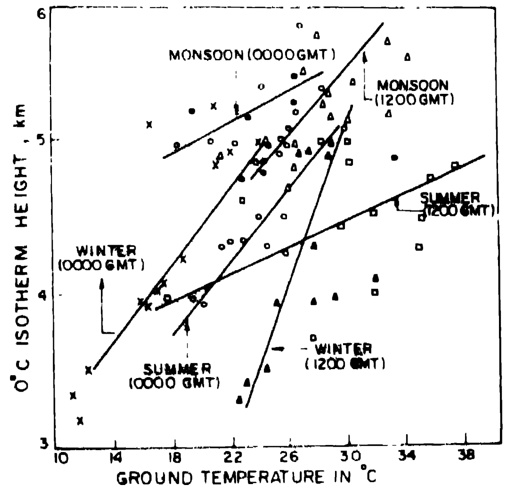

Figure 4. Effect of ground temperature on 0°C isotherm height

because there is not much variation in temperature, humidity and rainfall from season to season in Bangalore.

The effect of ground temperature on 0°C isotherm height is tested and shown in Figure 4. The open circles, crosses and solid circles represent the values of ground temperature (0°C) and 0°C isotherm height (km) during 0000 GMT in summer, winter and monsoon respectively. The solid triangles, open squares and open triangles represent the values of ground temperature (0°C) and 0°C isotherm height (km) during 1200 GMT in winter, summer and monsoon respectively. The plottings are done to see whether correlation exists between the ground temperature and 0°C isotherm height. The correlation between the ground temperature and 0°C isotherm height is poor when the data points of all seasons and times are taken together. However, plottings between the ground temperature and the 0°C isotherm height for different seasons and times are also done (viz., monsoon, winter and summer for 0000 GMT and 1200 GMT) and shown in Figure 4. It is seen that different regression lines can be drawn between the ground temperature and 0°C isotherm height when the data for different seasons and times are put together. Figure 4 indicates that the ground temperature varies from around 11°C to 24°C while 0°C isotherm height varies from around 3.3 km to around 5 km in winter during 0000 GMT. The ground temperature varies between ~ 20°C and 30°C and 0°C isotherm height varies between 3.8 km and 5.25 km in summer (pre-monsoon) during 0000 GMT. Figure 4 suggests that the 0°C isotherm height increases as the ground temperature increases in different seasons and times.

Rain height is a highly variable parameter over the Indian tropical stations. We have rainfall also due to thunder storm and low clouds in Indian tropics. The rainfall occurs due to thunder storm far above the 0°C isotherm height. Such heights are 10 km to 12 km. Rainfall occurring from such heights are associated with supercooled rain drops. The rainfall occurring from the clouds which are well below the 0°C isotherm height is also known as warm rains. Such rains are quite common in tropical stations particularly in north-eastern region of India. It may be mentioned here that the ratio of the rainfall due thunder storm to the total rainfall is very high over the Indian stations particularly over Calcutta and Delhi as compared to that over temperate regions. The above observation suggests that there is complexity towards the determination of effective rain height due to typical characteristics of the rainfall.

4. Derivation of 0°C isotherm height from theoretical models

The rain heights are also estimated by using the following relation given by Fedi [4] and compared with the results observed over the Indian latitudes. The relation given by Fedi is represented for 0.01% of isotherm height in a year.

$$H = 5.1 - 2.15 \log (1 + 10(\phi - 27)/25)$$

where ϕ is the latitude of the location in °N.

The isotherm heights deduced by using aforesaid equation over Bangalore, Calcutta and Delhi are 4.88 km, 4.63 km and 4.39 km. The values of H observed over India are found to be high compared to the results obtained by using Fedi's relation. Such observations are also reported from African tropical stations [1].

It is seen from the results of the probability distributions of rain rates deduced from the measurements over Delhi and Calcutta by using rapid response rain gauges [6] that the rain rate and logarithm probability follow linear relationship at high rain rates. The rapid response rain gauge measures rain fall in every 10 seconds. The maximum rain fall rate is recorded by the rapid response rain gauge is 250 mm/hr and the minimum is 2.5 mm/hr. The minimum and maximum limits of rain rate measurements are due to the minimum number of drops (one only) and the maximum number of drops that could be counted distinguishably. Such aforesaid observations between the probability distributions of rain rates are also reported by Crane [2] and the following relationship between rain rates and log of the probability distributions is presented.

$$H_R = a + b \log p,$$

where H_R is the isotherm height and p is the probability of distribution of the rain height.

The relationship is used for interpolation for the estimation of isotherm height for the probability levels between 0.001 and 1 percent of the year. It is reported by Crane [2] and Ajayi and Odunewu [1] that the average isotherm height during a period is assumed to correspond to that expected at 1% probability level while the highest rain height observed during the period is assumed to correspond to the value to be expected at 0.001%.

Based on the model suggested by Crane [2] results on isotherm height for three stations, *viz.*, Bangalore, Calcutta and Delhi for winter are estimated and presented in Figure 5. It is seen that the isotherm heights at 1% probability level are 5.07 km and 4 10 km and 3.40 km and at 0.001% probability level are 6.1 km and 4.7 km and 4.3 km over Bangalore, Calcutta and New Delhi respectively. The rain height over Delhi is less as compared to Bangalore and Calcutta during winter. However, this is not true for monsoon and pre-monsoon periods over Indian stations. But the aforesaid results pertaining to winter periods over Indian stations agree with the results reported from places where the climate is of temperate type.

It is reported in Rec ITU-R PN 839 [7] (CCIR recommendation, International Telecommunication Union, Geneva, Switzerland) that the mean 0°C isotherm height during rain conditions is 5 km for northern latitudes lower than 23° latitudes and $5 - 0.075\ (\phi - 23)$ km for northerly latitudes (ϕ) above 23°. The 0°C isotherm height derived by using the aforesaid relation given in Rec ITU-RPN 839 for Delhi whose latitude is 28.32° is found to be 4.585 km. It is important to mention here that the 0°C isotherm height during monsoon over Delhi is 4.3 km. It is important to mention here that the Rec ITU-R PN 839 may be used only for monsoon period over Indian stations. It is not valid for other seasons over Indian stations.

The estimation of effective height for modelling rain attenuation on an earth-space path by using the relation which is $\sim 3.0 + 0.028\phi$ km for latitudes (ϕ) less than 36° given in Rec ITU–R PN 618–2 [8] (CCIR recommendation, International Telecommunication Union, Geneva, Switzerland), is made for Bangalore (12.58° N), Calcutta (22.39° N) and Delhi (28.32° N). The estimated results are found to be 3.36 km, 3.63 km and 3.79 km for

Bangalore, Calcutta and Delhi respectively. The derived results on effective height for the three stations are found to be closer to the results on 0°C isotherm height observed during

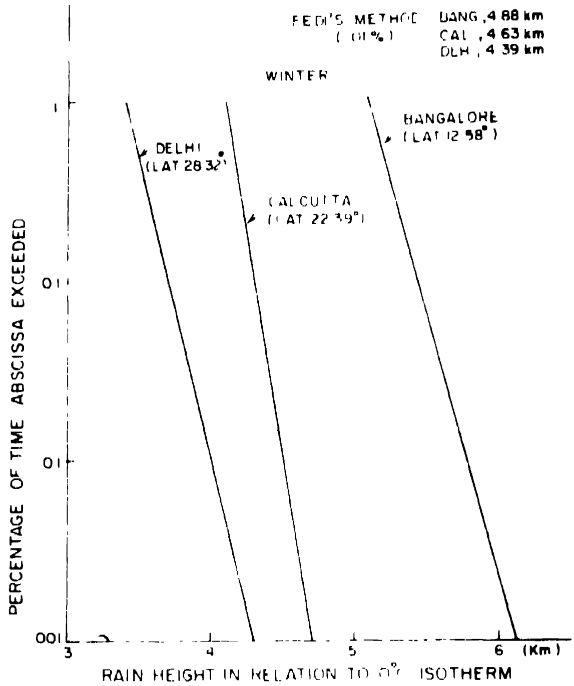

Figure 5. Distribution of 0°C isotherm height deduced on the basis of theoretical model for three selected stations during winter

winter months. The models on 0°C isotherm height and effective rain height which are developed on the basis of the temperate situations are applicable to the winter situations only in Indian tropical stations.

5. Estimation of specific and total attenuation using rain height in relation to 0°C isotherm height

The rain height is one of the most important parameters for the prediction methods of the attenuation of the radiowave due to rain for slant path. The rain is considered uniform from the ground to the rain height h_R, which is a function of the rain type. It is assumed to be equal to the 0°C isotherm height, $h_R = h_{FR}$ [1]. At present, measured values of h_{FR} [1–3], although accurate within their geographical domain, pose a major drawback since world wide unification can hardly be achieved.

The total attenuation due to rainfall along a slant path is given by CCIR [9]

$$A_R = \alpha(R)\, L_e,$$

where A_R is the attenuation exceeded for P % of time, $\alpha(R)$ is the specific attenuation.

The specific attenuation and the effective path length (L_e) are given as

$$(R) = aR^b \quad \text{and} \quad L_e = r_p \cdot L_S,$$

where R is the rain rate in mm/h, a and b are the constants which depend on frequency (CCIR, 1986), r_p is the reduction factor and L_S is the slant path below the rain height. The reduction factor, r_p is given as

$$r_p = \frac{90}{90 + C_p \cdot L_G},$$

where $C_p = 9$, 4, 0.5 and 0 respectively for 0.001%, 0.01%, 0.1% and 1% of time and L_G is the horizontal projection of slant path.

For elevation angles greater than 10° (which is usually the case in practice for earth space links)

$$L_S = \frac{h_R - h_0}{\sin\theta},$$

where h_0 is the height of the station above mean sea level, h_R is the rain height in relation to 0°C isotherm height. It is also assumed that the attenuation due to rain does not exist above h_R

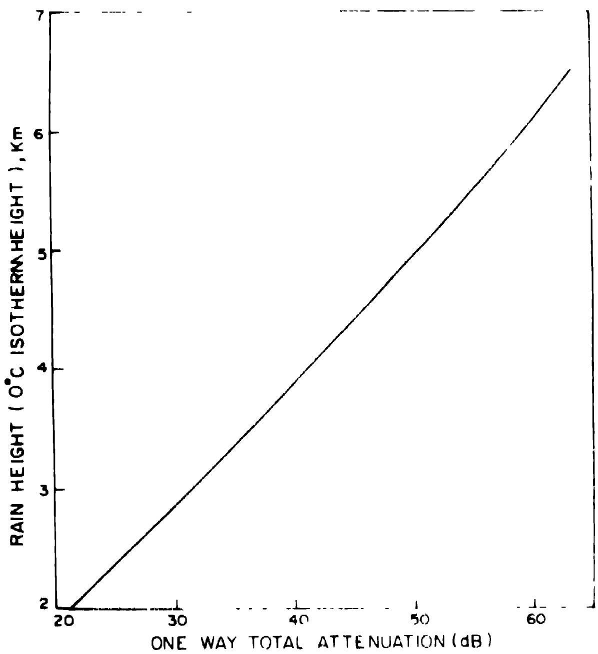

Figure 6. Variation of one way attenuation with height

Using the values of the coefficients a and b given in CCIR, 1986, the measured rain rate data and various given equations given in the aforesaid paragraphs, the 0°C isotherm height ($h_{FR} = h_R$), the total attenuations in dB/km over Delhi for the earth-space paths were estimated at 20 GHz. The attenuation due to rain has been estimated for rain rate 120 mm/h. Such rain rate (120 mm/h) over Delhi occurs for 0.01% of time. Such results were obtained by using a rapid response rain gauge. In order to show the effect of rain height (0°C isotherm height) on the attenuation of radiowave due to rain, the one way total attenuation for different rain heights of 2 km, 3 km, 3.5 km, 4.6 km, 5.9 km and 6.5 km has been estimated and presented in Figure 6. It is seen that the attenuation values are ~ 21.5 dB, 31.6 dB, 36.2 dB, 46.3 dB, 58 dB and 63.3 dB for rain heights ~ 2 km, 3 km, 3.5 km, 4.6 km, 5.9 km and 6.5 km respectively at ~ 20 GHz. The variation in attenuation is appreciable even while there is small change in rain height. It is seen that the attenuation is dependent on rain height. The actual rain height should be taken into account for the estimation performance interms of attenuation of radiowave due to rain for communication link operating in microwave and millimeter wave frequencies The measured values of 0°C isotherm height are sparse over the world including India. The efforts should be made to procure such results over different Indian stations.

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